

Report on

**SELENIUM SELECTIVITY
IN
ION EXCHANGE RESINS**

Prepared for the

**SAN JOAQUIN VALLEY
DRAINAGE PROGRAM**

Under contract with the

U.S. BUREAU OF RECLAMATION

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BOYLE ENGINEERING CORPORATION

consulting engineers | architects

This report presents the results of a study conducted for the Federal-State Interagency San Joaquin Valley Drainage Program. The purpose of the report is to provide the Drainage Program agencies with information for consideration in developing alternatives for agricultural drainage water management. Publication of any findings or recommendations in this report should not be construed as representing the concurrence of the Program agencies. Also, mention of trade names or commercial products does not constitute agency endorsement or recommendation.

The San Joaquin Valley Drainage Program was established in mid-1984 as a cooperative effort of the U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey, California Department of Fish and Game, and California Department of Water Resources. The purposes of the Program are to investigate the problems associated with the drainage of irrigated agricultural lands in the San Joaquin Valley and to formulate, evaluate, and recommend alternatives for the immediate and long-term management of those problems. Consistent with these purposes, Program objectives address the following key areas: (1) Public health, (2) surface- and ground-water resources, (3) agricultural productivity, and (4) fish and wildlife resources.

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ERRATA

Report on Selenium Selectivity in Ion Exchange Resins, February 1988, prepared for the San Joaquin Valley Drainage Program by Boyle Engineering Corporation under contract with the U.S. Bureau of Reclamation.

In Figures 2, 3, and 4 on pages 16, 17, and 18, respectively, the vertical coordinate in each case should have the dimensions of MILLIEQUIVALENTS PER LITER instead of MG/L.

SELENIUM SELECTIVITY IN
ION EXCHANGE RESINS

Prepared for the
San Joaquin Valley Drainage Program
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Under
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INTRODUCTION

This report relates to an initial study on the application of the ion exchange process to treatment of agricultural drainage water from the Kesterson reservoir area. The work was authorized by the U.S. Bureau of Reclamation on March 23, 1987, under Technical Service Agreement 5-CS-20-03270. It is believed that the ion exchange process will be found useful for removal of selenium, arsenic, boron and molybdenum. This report focuses on preliminary studies on selenium removal using selenium selective resins.

OBJECTIVE

The objective of this effort is to demonstrate that ion exchange resins can be formulated to be selenium selective. Boyle Engineering prepared resins are being studied for use in treatment of Kesterson type wastewater. Costs will be estimated for using this resin and two other resins, one of lesser and one of greater selectivity.

APPROACH

Laboratory tests were made with water samples containing appropriate concentrations of selenium, sulfate, chloride, and other ions to simulate Kesterson drainage wastewater. Bench scale column tests were also made with field samples of wastewater and synthetic water samples containing selenium and sulfate ions. Using the experimental selectivity data computer models were run to verify the column tests of the ion exchange process, to verify the advantages of selenium selectivity in column action and to validate use of the models in future process design.

SUMMARY OF RESULTS

1. Two strong base anion resins, both similar to a commercial type I resin (See Figure 1) but having larger alkyl groups in place of the trimethyl, showed selectivity for selenate ion over sulfate ion. This is a highly significant result because it indicates a promising methodology to adapt the ion exchange process to remove selenate ion from wastewater in the Kesterson drainage area. The selenium selective resins are similar to commercially available resins and can be manufactured in large quantities using existing full scale plant processes and equipment.

2. A further significant research finding is that the selenate to sulfate selectivity appears to be directly related to the size of the alkyl groups in the resin. This finding makes it reasonable to assume that greater selectivity may be found in other resins of this type with larger alkyl groups or with other similar resin structural changes.
3. Operating costs of using the most selective resin in this study using a simple ion exchange process were estimated to be under \$100 per acre foot for treating typical Kesterson drainage area wastewater. This is compared to the costs of using commercially available resins with no selenate to sulfate selectivity. These costs are estimated to be about \$200 per acre foot. The latter higher cost is due to the large amount of interfering sulfate ion in the wastewater.
4. Operating costs were projected for using resins having higher selectivity than those studied here and which may be possible to manufacture. It is reasonable to expect that costs as low as \$50 per acre foot or lower can be achieved. A further research effort is required to produce and test these resins. Three phases of future work are described to obtain this goal.
5. Several experimental problems were encountered in this brief study relative to this type of research. One problem was the time delay between the experiment and receiving the final analytical results because of the difficulty in performing reliable selenium analyses. A second problem encountered was selenium contamination of resin samples which gave erroneous resin performance data. The contamination was due to the repeated use of small amounts of resin. This problem would not occur if larger amounts of resin were available for study. A third problem was the complex ionic matrix of the Kesterson water samples which made the resin studies more complex than anticipated and obscured the selectivity data.

PREVIOUS WORK ON ION EXCHANGE REMOVAL OF SELENIUM

The use of ion exchange for removal of inorganic species of selenium from water has been demonstrated to be effective in water having low ionic strength such as is encountered in drinking water. In Reference 1 it was demonstrated that selenite ion is removed from water using strong base anion exchange resins and is similar in selectivity to nitrate ion, but sulfate is the preferred ion and will interfere in selenite removal. Selenite can also be removed efficiently by other absorbers, offering an alternative method if sulfate interference is too high. In Reference 2 it is reported that

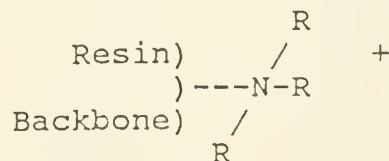
the prior conversion of selenite by oxidation to selenate gave an efficient removal of selenium as selenate. It was pointed out in both Reference 1 and 2 that selenate and sulfate are non-selectively absorbed on the strong base anion exchange resins studied, consequently, sulfate is simultaneously removed with selenate. This effectively reduces the efficiency of the process in direct proportion to the amount of sulfate.

The major problem associated with the Kesterson drainage water is the trace amount of selenium, which is present mainly as selenate ion, in concentrations of approximately 0.3 mg Se/L. Large concentrations of sulfate ion pose extraordinary difficulty for removal of selenium by the ion exchange process. Agricultural drainage water from the Kesterson area is very high in sulfate ion. Concentrations of 3000 mg/L were in the samples studied in this program. See Appendix. This concentration is 20 to 50 times higher than the sulfate found in groundwater supplies. The ratio of sulfate to selenium is of the order of 10,000 to 1. The desired product would have a ratio of approximately 1,000,000 to 1 or greater.

To accomplish this degree of selenium selectivity in an ion exchange process requires a resin capable of exchanging selenate in preference to sulfate ion. A study supported by U.S.B.R. (Reference 3) concluded that the synthesis of a selenate selective resin would be highly desirable and may be possible. Reference 3 contains a discussion by Gerhard Klein on the advantages which would result if selenium selective resins were used in the clean up effort of the Kesterson reservoir.

A study of resin features that control ion selectivity was initially done in an EPA supported study (Reference 4). Further work was done in the Boyle Engineering laboratory (Reference 5 and 6). This latter study with a series of structurally related resins demonstrated that resins lost their sulfate affinity as the alkyl group surrounding the amine nitrogen progressed from methyl through to butyl whereas the resin retained relatively high affinity for chloride and nitrate. See Figure 1.

Figure 1. Trialkyl Anion Exchange Resin



R = alkyl group. For Type 1 resin, R = methyl.

The author (Reference 5) has offered the theory that the larger R groups make the bonding to a divalent ion difficult by causing steric hindrance between the two ion exchange sites, thus preventing two ion exchange sites from approaching the divalent sulfate ion to form a bond of normal stability. This difficulty would not exist with a monovalent ion. An extension of this theory to predict the relative affinity between two divalent ions was made. It was predicted that a divalent ion larger than sulfate would form a more stable bond at an ion exchange site by relieving steric strain between the two ligand moieties. This theory was tested in our laboratory with selenate ion which is slightly larger by approximately 10% greater radius, Reference 3.

The tests done at Boyle prior to this U.S.B.R. study indicated that tributyl resin was selective for selenate over sulfate. The tests done under this contract and as reported below confirm these findings and demonstrate the trend among the resins.

RESINS TESTED

The rationale for selection of resins for these studies was to avoid exotic type resins which would require lengthy or unusual methods of preparation and use only resins which can be easily manufactured by existing commercial processes and plant equipment. Boyle Engineering Corporation has developed a close working relationship with manufacturers of commercial resins. Through working agreements special resins are prepared according to specifications in consultation with the manufacturers and by procedures which can use existing manufacturing methods.

The resins used in this study and the properties are listed in Table 1. K(NC) and K(NS) are nitrate to chloride and nitrate to sulfate selectivity coefficients.

TABLE 1. RESIN PROPERTIES

No.	Amine	Commercial Resin Base	% Moisture	Vol. Cap.	K(NC)	K(NS)
A-101D	trimethyl	A-101D	48-55	1.3	3	25
11	tripropyl	A-104	33.0	1.16	20	1,000
12	tributyl	A-104	30.4	.661	6	11,000

The first resin is listed as a reference resin to which the properties of the other resins can be compared. The A-101D is a designation of the commercially available resin. Resin 11 and 12 are experimental resins. These resins were obtained from Duolite International.

The experimental resins were prepared from the polymerized styrene DVB base material from which the commercial resin A-104 was prepared by the same company. These two resins are a part of a larger series of resins prepared from the same base.

The amine referred to in Table 1 is the amine used in the amination step to form the quaternary amine of the anion exchange resin structure. Moisture contents of the dried resin beads and nitrate and sulfate selectivity coefficients are listed for comparison.

ANALYTICAL PROCEDURES. QAQC

Chemical analyses were performed by a local laboratory certified by the State of California to perform water and wastewater analyses. The laboratory chosen uses modern instrumentation methods. When samples were submitted the method of analysis was specified. Also, duplicates were frequently submitted. The samples from Kesterson reservoir were submitted with instruction to perform the selenium analyses by the double reduction method to the hydride form for flame photometry recommended in Reference 7.

In cases where synthetic mixtures were prepared containing higher levels of selenium, either ion chromatography or emission spectrophotometry was specified as the analysis method. In some cases both were specified.

PRELIMINARY WORK AND BINARY ISOTHERM TESTS

Several tests were made with solutions of known composition and measured quantities of resin. The objective of these tests was to determine the equilibrium conditions between species in the aqueous and resin phases as expressed by an equilibrium constant. The conditions of the tests are shown in Table 2.

In each case the resin was in the chloride form at the start of the experiment.

The appropriate equilibrium expressions, (1) and (2) are as follows:

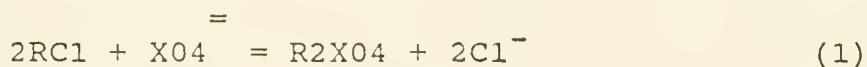
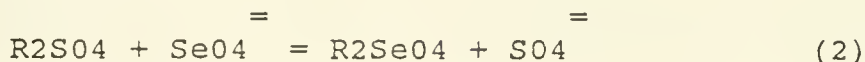


TABLE 2. CONDITIONS OF EXPERIMENTS

<u>Experiment Number</u>	<u>Solution Number</u>	Total Anion meq/L	<u>Ions Present in Starting Solution</u>			<u>Resin Used</u>
			<u>SeO4</u>	<u>SO4</u>	<u>Cl</u>	
1	1	56	x	x	12	
1	2	56	x	x	A-101D	
2	1	20	x		12	
2	2	20		x	12	
3	1	150	x		12	
3	2	150		x	12	
4	1	10	x		11	
4	2	10		x	11	
	3	10	x		12	
	4	10		x	12	
5	1	62	x	x	A-101D	
6	1	20	x	x	12	
Computer Simulated Test of Expt 6						
7		20	x	x		
Computer Simulation of Kesterson Sample						
8		92	x	x	x	
					(+ nitrate)	

where $XO_4^{=}$ is either selenate or sulfate in the aqueous phase and $RC1$ and $R2XO_4$ are in the resin phase. Equation (2) is a simple exchange reaction.



The related equilibrium constants are:

$$K(Se04, C1) = \frac{R2Se04 \times (C1^-)^2}{Se04 \times RC1^2} \quad (3)$$

$$= K(Se, C) \quad (4)$$

$$K(S04, C1) = \frac{R2S04 \times (C1^-)^2}{S04 \times RC1^2} \quad (5)$$

$$= K(S, C) \quad (6)$$

$$K(Se04, S04) = \frac{R2Se04 \times S04}{R2S04 \times Se04} \quad (7)$$

$$= K(Se, S) \quad (8)$$

In all cases concentrations are expressed as milliequivalents per liter. In cases where selenate and sulfate were not present in the same solution the respective chloride selectivity constants were calculated from the data. The $K(Se, S)$ values were then calculated from the ratios of the chloride constants.

EXPERIMENT 1.

A stock solution containing 25.56 meq/L of $Se0_4^{=}$ and 30.21 meq/L of $S0_4^{=}$ were prepared. Ten ml of A-101D and resin 12 were placed in separate bottles. To each bottle, measured quantities (500 ml and 254 ml) of the stock solution were added and allowed to equilibrate for 48 hours. Samples of each solution were

submitted for analyses. The results provided values for the equilibrium constants as follows:

$$\begin{aligned}K(\text{Se},\text{S}) &= 1.18 \text{ for A-101D} \\ &= 2.70 \text{ for resin 12}\end{aligned}$$

a repeat experiment using ion chromatography as the analytical method gave

$$K(\text{Se},\text{S}) = 3.94 \text{ for resin 12}$$

EXPERIMENT 2.

In this experiment separate sulfate and selenate solutions were prepared having concentrations of approximately 20 meq/L. One liter of each solution was separately equilibrated with 10 ml of resin 12 in the chloride form. The contents of each of the two solutions were sampled and analyzed as well as samples of the stock starting solutions. The analytical results provided the data for the following chloride selectivity coefficients.

$$K(\text{Se},\text{C}) = .0803$$

$$K(\text{S},\text{C}) = .0141$$

From these two constants, $K(\text{Se},\text{S})$ is calculated as 5.71. A repeated series of analyses gave 6.27.

EXPERIMENT 3.

The above experiment was repeated with solutions having a total anion concentration of 150 meq/L. Equivalent volume quantities of resin and solution were equilibrated. The values for the selectivity coefficients obtained are:

$$K(\text{Se},\text{C}) = .137$$

$$K(\text{S},\text{C}) = .060$$

$$K(\text{Se},\text{S}) = 2.30$$

EXPERIMENT 4.

The selectivities of resin 11 and resin 12 were compared in this experiment in solutions containing approximately 10 meq/L total anion concentrations. This also extends the series of anion concentrations studied for resin 12. Separate selenate and

sulfate solutions were used to determine the $K(X,C)$ values as in the above two experiments. The values determined are:

Resin 11

$$K(\text{Se},\text{C}) = .0018$$

$$K(\text{S},\text{C}) = .0012$$

$$K(\text{Se},\text{S}) = 1.5$$

Resin 12

$$K(\text{Se},\text{C}) = .042$$

$$K(\text{S},\text{C}) = .019$$

$$K(\text{Se},\text{S}) = 2.21$$

COLUMN TESTS

From the above experiments, it was apparent that resin 12 showed selenate selectivity over the sulfate ion. However, the significance of the absolute values of the selectivity coefficients to actual column action and use in a process needed to be assessed. A sample of Kesterson drainage water was obtained from the Murieta Farms station for tests. The analysis of the sample is given in the Appendix.

Two column tests were planned: one with only sulfate and selenium and a second with the Kesterson sample. The first test, described below, demonstrated with remarkably striking results that column action is able to effectively remove selenate from sulfate. A subsequent test using the Kesterson sample with the same apparatus, glassware and column was inconclusive because of selenium contamination. Large amounts of selenium, several times the amount in the feed water, were found in the product water. Because sufficient sample for a second column test was not available, a multi-component isotherm test was then conducted to duplicate the first resin plate on the column and a computer generated effluent history was developed to simulate Kesterson water flow through a bed of resin 12. A separate test was conducted with A101D as a control.

Column Test 1 (Experiment No. 6)

A glass column (0.6 inch ID) containing 177 ml of resin No. 12 (43 inch depth) in the chloride form was set up with a

peristaltic pump. A solution approximately 10 meq/L in sodium sulfate and 10 meq/L in sodium selenate was prepared as feed solution and pumped through the column at a rate of .3BV per minute. Measured quantities of effluent were placed in a numbered series of sample bottles for analysis. Sulfate breakthrough was monitored in the effluent to determine where samples were to be taken to obtain more detailed data on breakthrough. The samples were submitted to the laboratory for analyses of sulfate and selenate. The effect of flow rate was not investigated.

The results of the column test are shown in Figure 2. Sulfate ion is the first to breakthrough and rises to a value higher than its input value. This is a classical type curve for breakthrough of an ion being displaced from the column by an ion of greater affinity. In this case, the selenate ion has the greater affinity. The sulfate breakthrough is at about 25 bed volumes and selenate breakthrough is at about 47 bed volumes. The curves are similar to those obtained when the competing ions are nitrate and sulfate on a type I resin where nitrate breaks through first followed by high nitrate peak prior to sulfate breakthrough.

COMPUTER GENERATED BREAKTHROUGH CURVES. (EXPERIMENTS 7 AND 8)

The above experiment was simulated on the Boyle Engineering Corporation ion exchange simulator program. The curve using the $K(\text{Se},\text{S})$ value of 2.5 is shown in Figure 3. The experimental points from the above experiment are also plotted for comparison. The agreement between the experimental curve and the experiment shows the validity of using the simulator program in predicting breakthrough curves, providing the proper selectivity coefficients are used.

A second simulation was run using the following constants on a water of the composition of the Kesterson area drainage water composition. See Appendix.

$$K(\text{Se},\text{Cl}) = .042$$

$$K(\text{S},\text{Cl}) = .019$$

$$K(\text{N},\text{S}) = 5$$

The results are shown in Figure 4. The curve shows early breakthrough of the sulfate ion with a non-sharpening front followed by slow breakthrough of selenium with a self-sharpening front.

TABLE 3. COMPARISON OF EXPERIMENTAL AND PREDICTED CONCENTRATION VALUES IN MULTICOMPONENT ISOTHERM TESTS

<u>Component</u>	<u>Predicted</u> *	<u>Found</u>
A-101D Resin		
=		
<u>SeO4</u>		
Resin	2.41	2.49
Aqueous	.052	.0455
=		
<u>S04</u>		
Resin	470	464
Aqueous	14.94	15.62
Resin 12		
=		
<u>SeO4</u>		
Resin	1.46	1.46
Aqueous	.147	.146
=		
<u>S04</u>		
Resin	201	172
Aqueous	41.8	44.79

* Predicted by computer simulation using for
A-101D, $K(\text{Se,S}) = 1.0$ and for
Resin 12, $K(\text{Se,S}) = 2.4$
Concentrations in meq/L

MULTI-COMPONENT ISOTHERM TEST. (EXPERIMENT 5)

To confirm the validity of the above simulation a solution containing 3000 mg/L of sulfate and 1 mg/L of selenate was equilibrated with a measured volume of resin No. 12 in the chloride form. These concentrations were chosen to simulate the Kesterson drainage water. A control test was conducted with A101D. (The 3-fold higher selenium was chosen to obtain more accurate analyses). This equilibration can also be simulated by the Boyle Engineering computer programs and represents the first multi-component isotherm on a column. The value for $K(\text{Se},\text{S})$ of 2.4 was assumed. The experimental and predicted values are shown in Table 3.

In the case of resin 12, these data show that the ratio of resin bound selenium to aqueous selenium is of the order of 10/1 in both the experimental and predicted results. Whereas, the same ratios for sulfate ion are on the order of 4/1 or 5/1. Thus showing that selenium will concentrate on the resin to a greater degree than sulfate even in the presence of excessive amounts of sulfate. This effect is not shown in the data for A 101D to the same degree*.

DATA EVALUATION

The variance in the above experimentally derived selectivity coefficients can be due to several factors. Experimental errors can cause the values to deviate considerably. When constants were based on the chloride analyses checks were also made with the disappearance of the other ion (selenate or sulfate). The exponential terms in equations 3 and 5 magnify the error if only chloride is used for the calculation (a 5% error in chloride measurement can cause a 50 percent error in the calculated selectivity constant). Multiple analyses of the other ions were made to prevent reliance on chloride analyses alone and to keep these exponential errors as low as possible. The repeated results in a range of experiments reported tends to center around values of $K(\text{Se},\text{S})$ of 3 for resin 12. A further problem with chloride analyses is the leaching of chloride from the resin. To minimize this error the resins were exhaustively washed in DI water prior to use and chloride blanks were run with the resin in DI water with each experiment where chloride analyses were critical.

*The data also indicate that the selenium loadings for the two resins are 2.5 and 1.5 meq/L.

Other variances can be attributed to the range of ionic strengths used being from 10 meq/L to 150. This is a vast range over which it cannot be assumed that ion activities will be constant.

COST ESTIMATIONS

Preliminary cost estimates on the effect of using selenate selective resins can be made based on these tests. The major cost savings will be on the amount of salt used as regenerant. An estimate of the amount of salt was made based on the following assumptions.

1. The resin bed will be removed from service and placed into regeneration when it is close to saturation with sulfate and selenate ions.
2. At this time it is believed a process can work efficiently without removing all nitrate from the bed. This will save a considerable salt expense. The nitrate in the wastewater, which is quite high, will not be completely removed from the bed in the regeneration step. Although nitrate will pass through the column in each case and some will remain on the resin, the bed will be regenerated to remove only sulfate and selenium.
3. The ratio of selenium to sulfate on the spent bed and in the spent regenerant will be the same as the $K(Se,S)$ selectivity constant and is assumed to be 1.0 for the reference commercial resin.
4. The difference between the commercial resin and the selenium selective resins as far as their breakthrough characteristics are concerned will not be taken into consideration. The difference is that the commercial resins will give a sharper breakthrough curve. This difference must be dealt with in the process design which is yet to be developed and demonstrated.

The following results of a brine requirement calculation for a commercial resin were made.

Raw Water Composition:

Nitrate	567 ppm
Sulfate	2950 ppm
Chloride	1149 ppm
Bicarbonate	300 ppm
Resin Cap.	1.4 eq/L

Useful Bed Volumes of Product:	19
Bed Vol. of NaCl (12%) needed	.425
% of product used as brine	2.2
Pounds NaCl/1000 gal. product	30.2
Salt cost per A/F	\$157

It is assumed that an additional \$30 per A/F would be required for other operating costs. This is based on the experience gained in the operation of ion exchange plants in McFarland, CA.

The costs for a selenium selective resin will be lower due to the ability of the resin to concentrate selenate more than sulfate. The salt costs and amount of waste brine will be reduced inversely to the selectivity coefficient. The listing below shows the relationship.

<u>Resin</u>	<u>Selectivity Coefficient</u>	<u>Salt Cost \$ Per A/F</u>	<u>% of Product As Waste Brine (12%)</u>
Commercial	1.0	157	2.2
Boyle	2.0	78.5	1.1
Boyle	2.5	62.8	.9
Boyle	3.0	52.3	.7
	4.0	39.3	.6
	5.0	31.4	.4
Target	10.0	15.7	.2
	20.0	7.9	.1

The above cost estimates are based on the information developed in this report and are reasonable on what is now known. No engineering cost data has been obtained to verify these estimates through pilot plant tests. Assumptions are made that all process efficiencies are high and a suitable process can be worked out to efficiently use the selenium selective resins. No costs are included for brine disposal. The waste brine volumes are minimum numbers and represent only brine waste at 12% solids. Resin wash water quantities are not listed. It appears that only small amounts of wash water will be required as the product water is high in TDS and tailings may be returned to feed water sources.

Capital costs are also not included in the above cost data.

The advantages of the selenium selectivity are apparent in reducing both operating costs and amount of waste water produced.

FUTURE WORK

The effort described above demonstrates that strong base anion exchange resins can be made to selectively remove selenate ion from water which also contains large amounts of interfering sulfate ion. Future work must be performed to optimize the selenium selectivity of the resins, to obtain a higher removal efficiency and a lower operating cost, and to develop a process which can effectively use the selectivity properties. It is envisioned that future work would be done in three phases.

PHASE 1.

This will be an extension of the work described in this report. Laboratory work will be continued to study a larger series of resins to better delineate the important structural properties which contribute to selenium selectivity. The series of resins will be developed by making gradual structural changes introduced during the synthesis procedure. The commercial feasibility of manufacturing the resins on a large scale will be one of the main considerations for choosing resins for this study phase.

This phase will also include work on modifications of the ion exchange process to adapt the selenium selective resins to treatment of agricultural wastewater as found in the Kesterson drainage area. This will require laboratory work using ion exchange columns in the treatment chains to be tested. Minimization of wastewater production from the process will be one of the main factors to be studied here.

PHASE 2. PILOT PLANT

During this phase a pilot plant study will be conducted. A plant using the most feasible resin and process as developed above will be designed and operated. The pilot plant will be located in the Kesterson area and will use actual drainage water obtained at the site. It is presently envisioned that the pilot plant will treat approximately 10,000 gallons per day. The performance of this plant will be studied carefully to determine costs of operation and to develop further engineering information for design of a full scale demonstration plant.

PHASE 3. DEMONSTRATION PLANT

This will be the final phase and will result in the design, construction, and operation of a full scale pilot plant based on the most successful resin and process determined in the above phases.

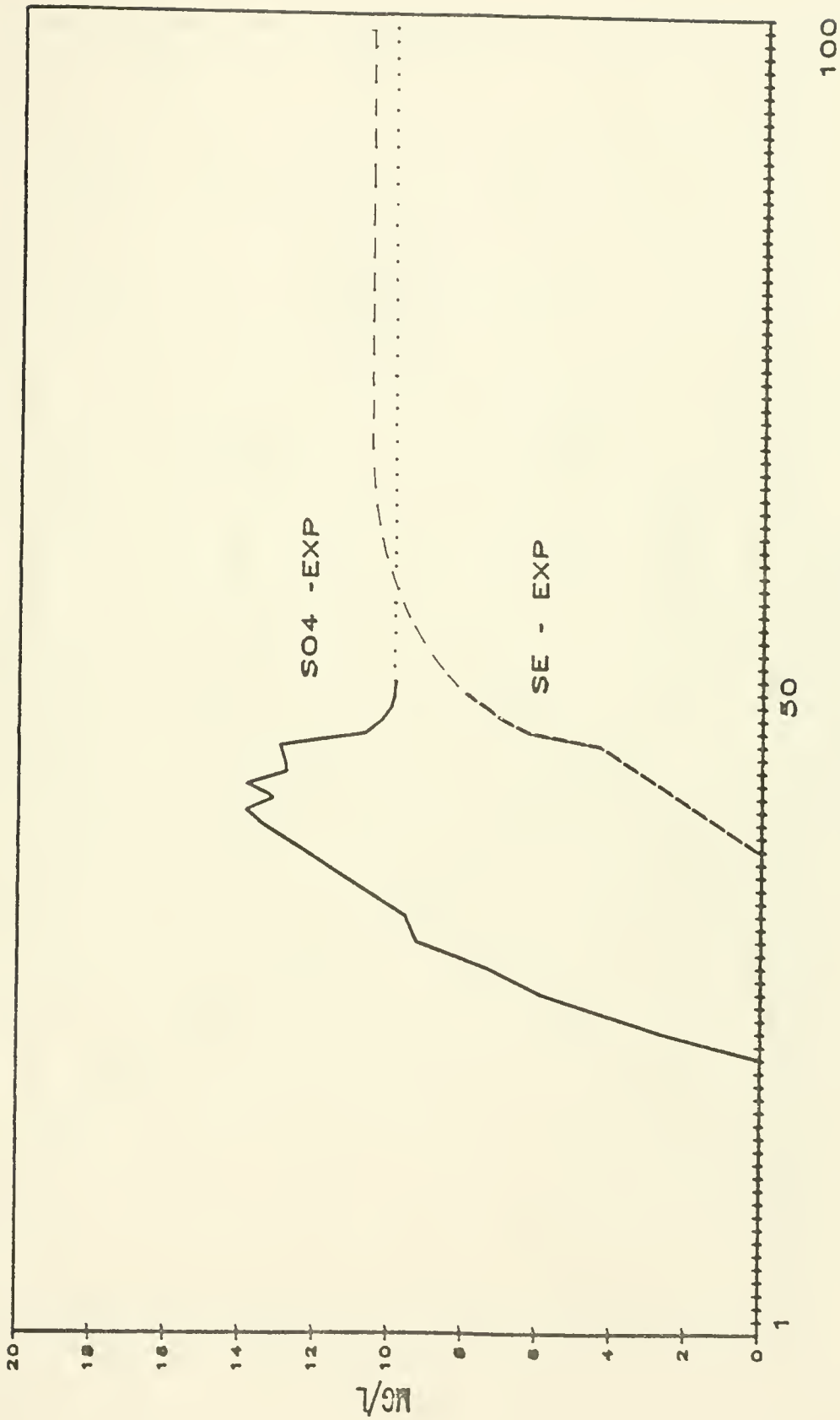
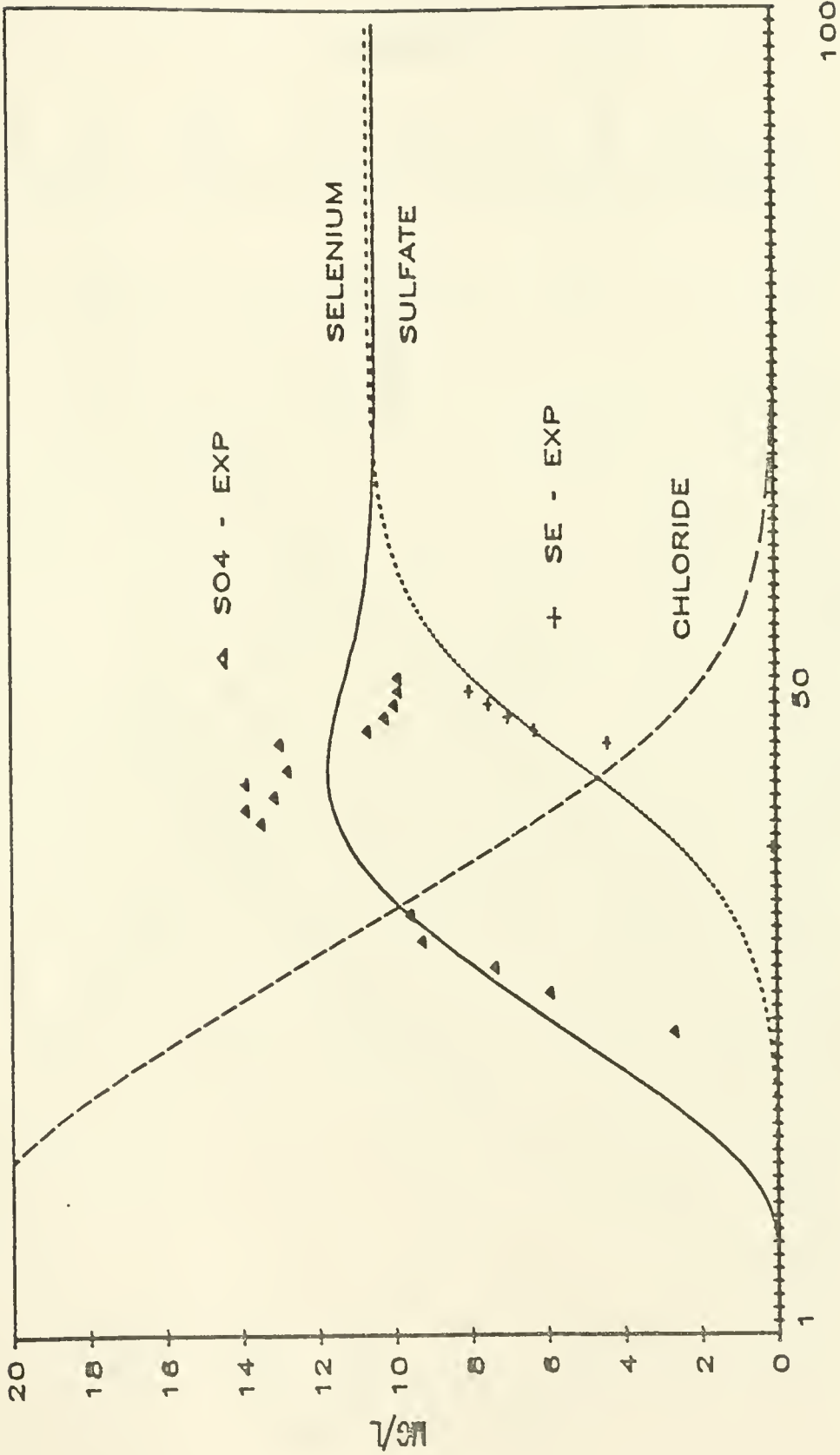


FIGURE 2. RESULTS OF COLUMN TEST 1.

These are experimental breakthrough curves (solid and dashed lines) using a column of resin 12, initially in the chloride form, and a feed solution containing approximately equal quantities of selenate and sulfate ion (10.7 meq/L selenate and 10.3 meq/L sulfate). Breakthrough and peaking of sulfate before selenate breakthrough confirms selenium selectivity property of resin 12. Extended lines show approximate feed concentration of both ions.



BED VOLUMES

FIGURE 3. COMPARISON OF COLUMN TEST 1 WITH COMPUTER GENERATED CURVES.

Computer generated breakthrough curves using ten theoretical resin plates of resin 12 and a selenate-to-sulfate selectivity of 2.2 are compared to the experimental data of Column Test 1 (See Figure 2). Data shows that a sharper separation of selenium and sulfate were obtained than is predicted by computer generated curves.

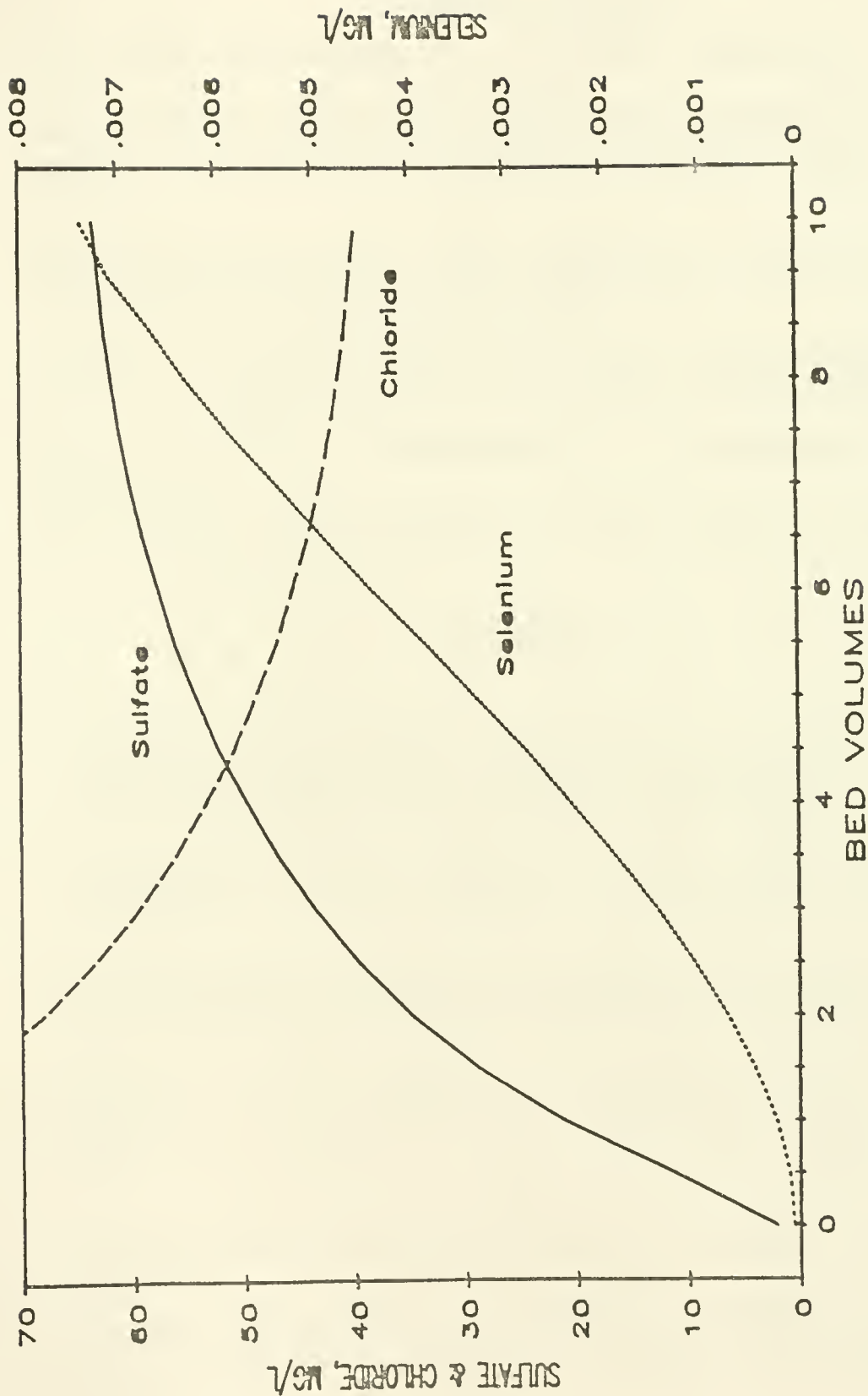


FIGURE 4. COMPUTER SIMULATION OF TREATING KRESTERSON WASTEWATER WITH RESIN 12.

Curves show prior breakthrough of sulfate with non-sharpening front and slow breakthrough of selenate with apparent self-sharpening front. Ten theoretical resin plates used. Potential of sharp separation with higher number of theoretical plates is shown.

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APPENDIX

Submitted by: Boyle Engineering
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 Attn: Dr. Guter

Date Reported: 6/26/87
 Date Received: 6/22/87
 Laboratory No.: 11923

Sample Description: Drainage Water from Kesterson reservoir area

WATER ANALYSIS

<u>CONSTITUENTS</u>	<u>mg/liter</u>	<u>DESIRABLE LIMITATIONS</u>
Calcium (Ca)		
Magnesium (Mg)		125.
Sodium (Na)		350.
Potassium (K)		-
Carbonate (CO ₃)		25.
Bicarbonate (HCO ₃)		250.
Chloride (Cl)	1149.	250 - 500 (600 short term)
Sulfate (SO ₄)	2950.	250 - 500 (600 short term)
Nitrate (NO ₃)	567.	45.
Fluoride (F)		1.0
Iron (Fe)		0.3
Manganese (Mn)		0.05
Arsenic (As)	(-) 0.01	0.05
Copper (Cu)		1.0
Zinc (Zn)		5.0
TDS		0.5
Hardness as CaCO ₃		200 ppm medium hard, 50-100 ppm very soft
Total Solids		500 - 1000 (1500 short term)
pH	7.8	
Electrical Conductivity		
micromhos/cm (K x 10 ⁶) @ 25°C	8700.	900 - 1600 (2200 short term)
Color		15
Odor		3.0
Turbidity		5.0 NT Units
Barium (Ba)		1.0
Cadmium (Cd)		0.010
Chromium (Cr)		0.05
Lead (Pb)		0.05
Mercury (Hg)		0.002
Selenium (Se)	0.305	0.01
Silver (Ag)		0.05
Boron (B)	7.3	
Molybdenum (Mo)	(-) 0.10	

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